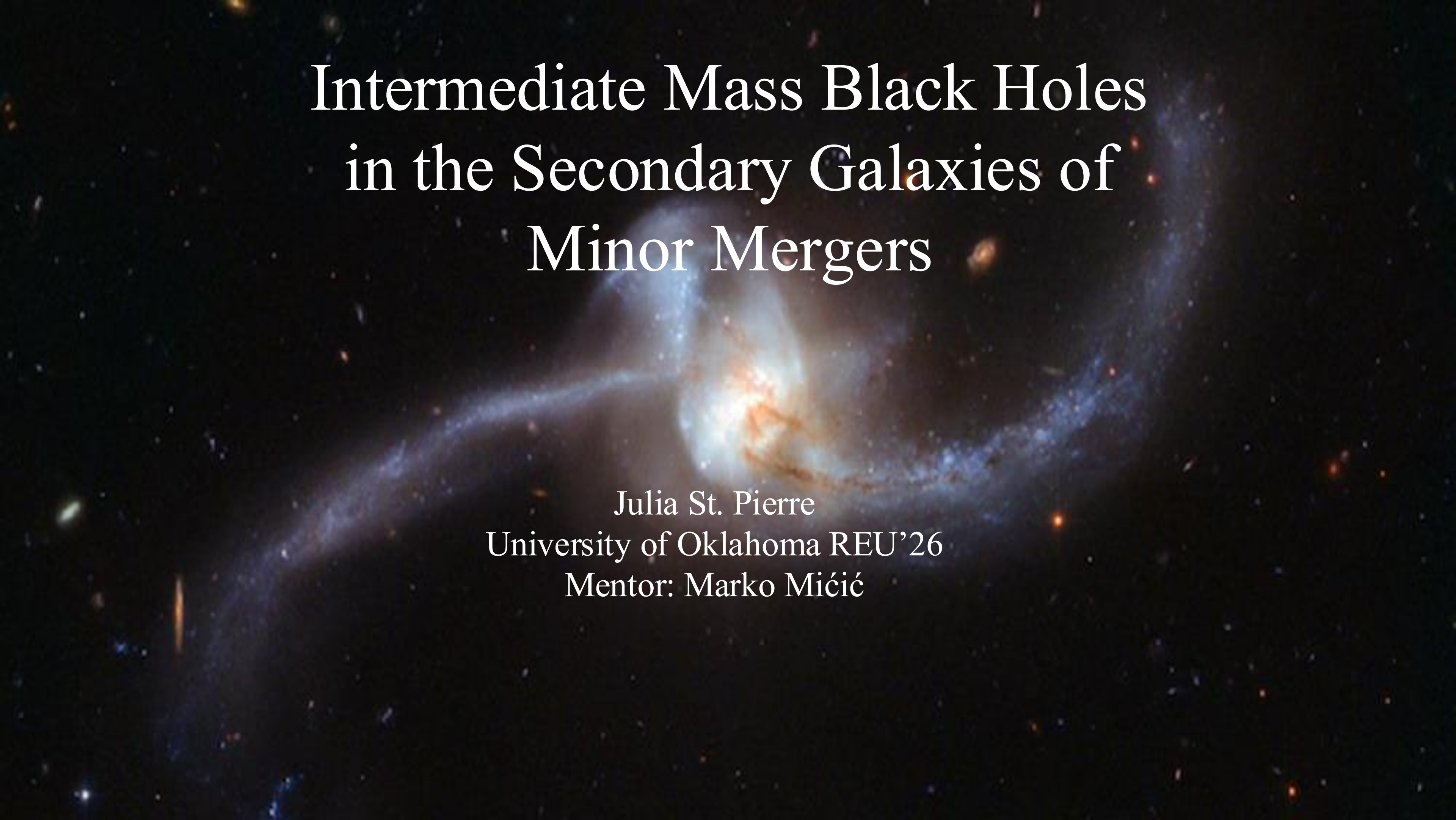

Intermediate Mass Black Holes in the Secondary Galaxies of Minor Mergers

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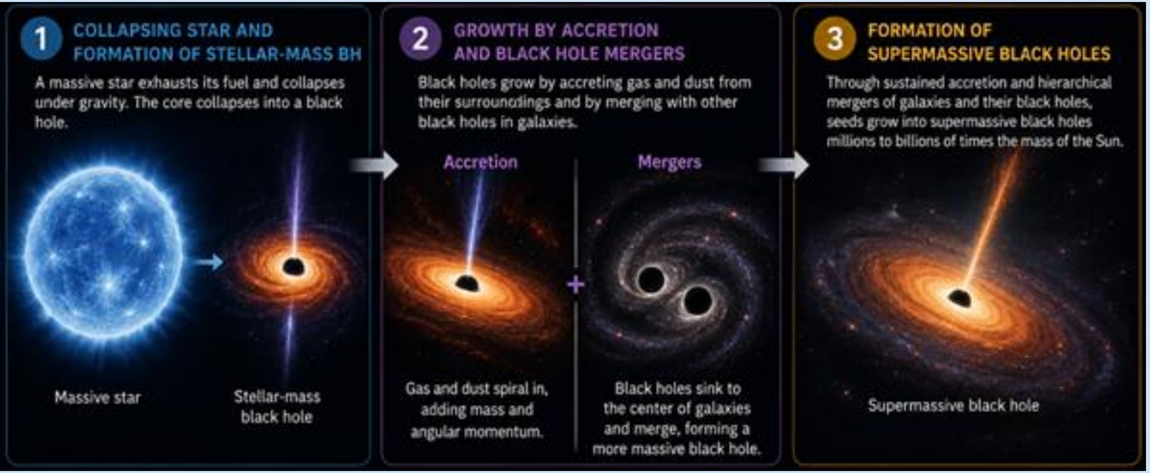
What are black holes? What are intermediate mass black holes?

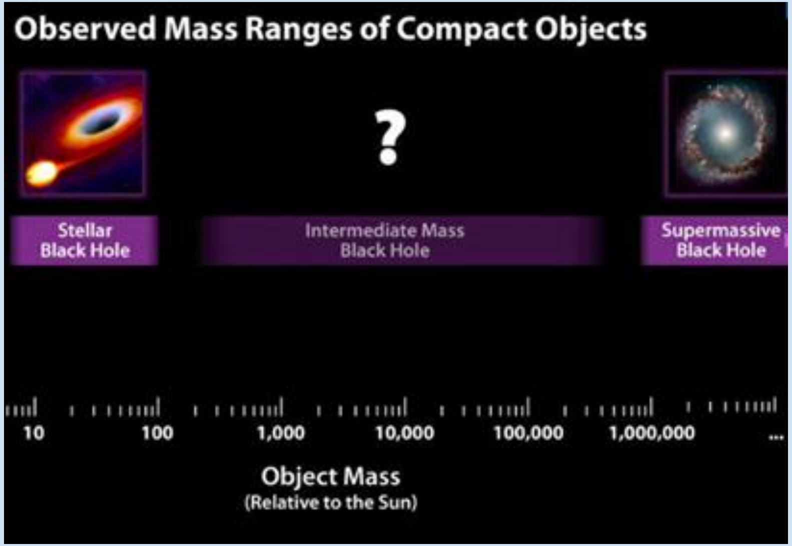
- Stellar mass black holes are between one and one hundred solar masses
- Formed from the collapse of a massive star
- Supermassive black holes can be millions to billions of solar masses
- Reside at the center of galaxies

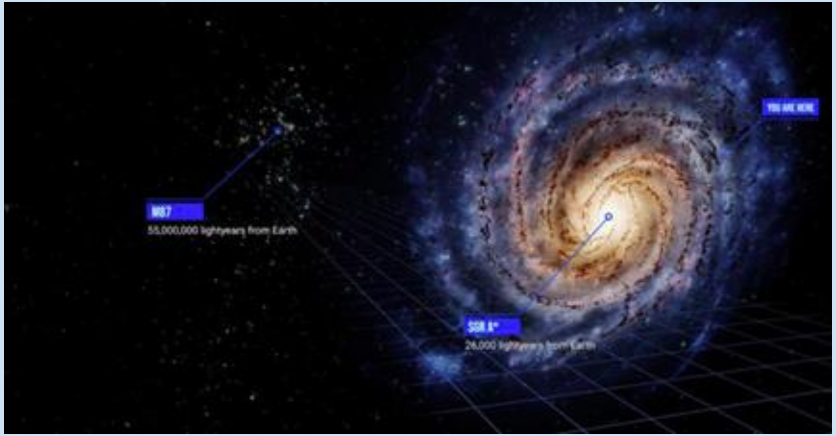


- Mergers and accretion allow small black holes to achieve supermassive size
- Expect a left over population of intermediate mass black holes (IMBHs)
- Between one hundred and one hundred thousand solar masses

Where would IMBHs be located?

- Black hole mass scales with host galaxy mass
- Dwarf galaxies: gas clumps together + low surface density
- Dwarf galaxies are expected to host faint or dormant IMBHs
- Low accretion leads to low emission





Credit: National Science Foundation/Key L, NASA/JPL-Caltechi

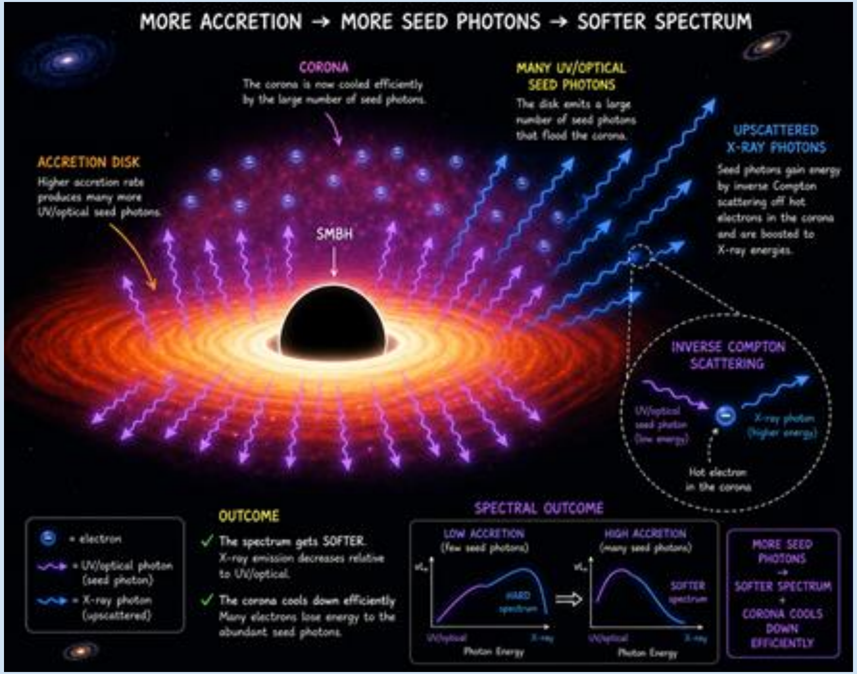
Why look at minor mergers?

- Minor mergers: the large primary galaxy is undisturbed while small secondary galaxy undergoes intense changes
- Accretion bursts at pericentric passage: presence can be observed
- The secondary galaxy in a minor merger hosts the actively accreting intermediate mass black hole

Credit: Pearson

How are IMBHs detected?

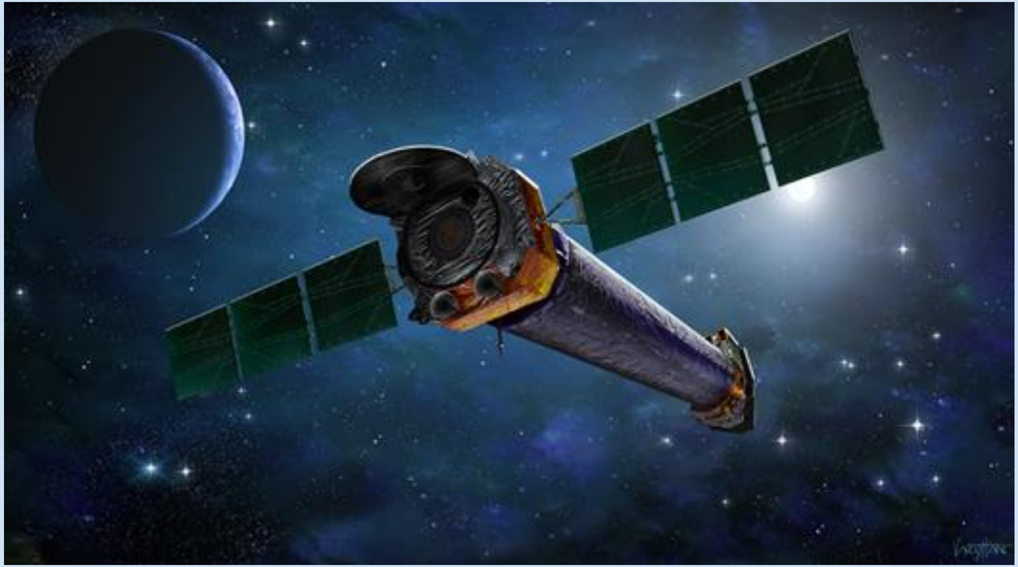
- Accretion disk emits seed photons
- Pass through the corona and undergo energy up-scattering
- The observational signature produced is a hard X-ray power law spectrum
- Increased accretion rate results in the corona being: overwhelmed, cooled, and collapsed
- The observational signature is a thermal blackbody spectrum that peaks in the soft x-ray band



Courtesy of M. Mićić

What data is being used?

- Chandra Deep Field South
- Hundreds of deep space observations
- Spans over 17 years
- Over 7 million exposure seconds
- Faint object detection
- Three candidates

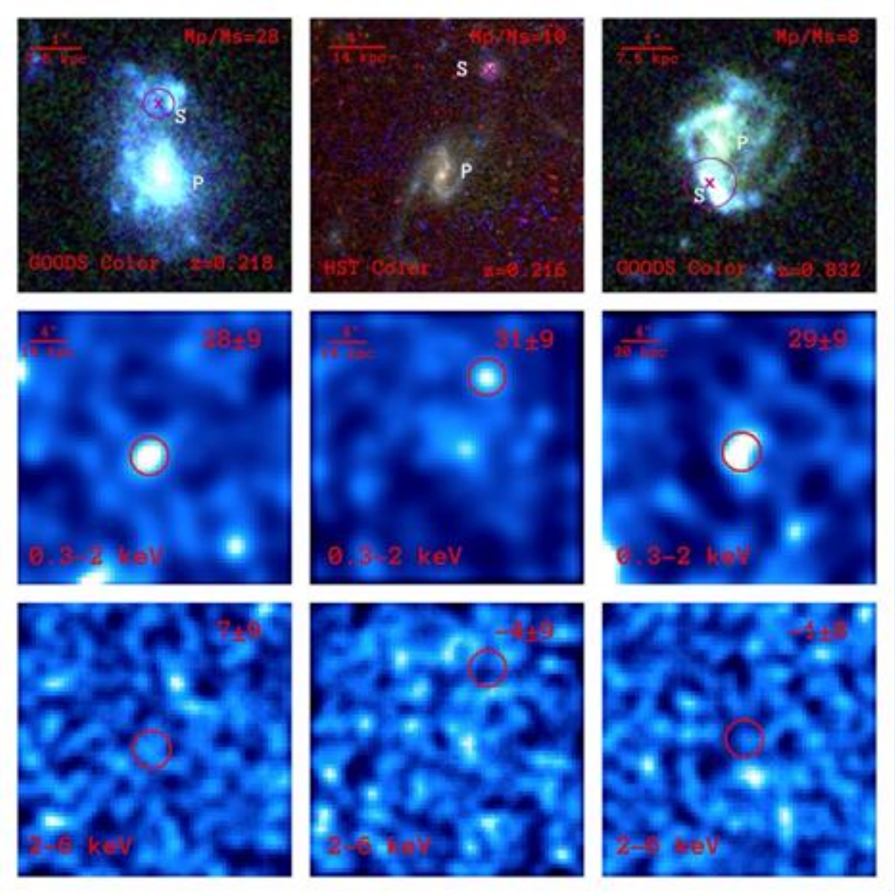


Credit: NASA/CXC & J.Vaughan

How will the data be used?

- Redshift, z = 0.216
- Images were energy filtered
- Cropped
- Stacked

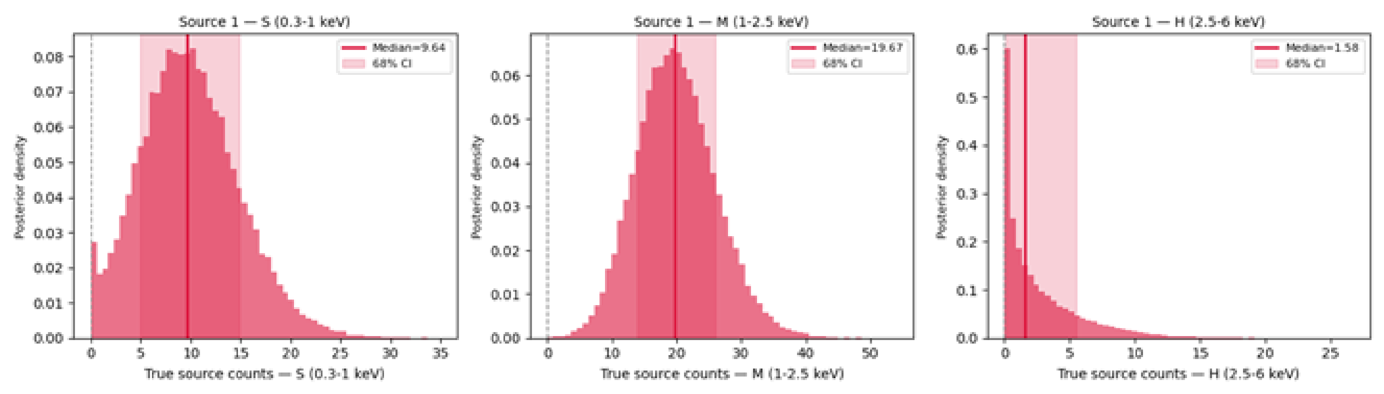
Soft band:	0.3 – 1.0 keV
Medium band:	1.0 – 2.5 keV
Hard band:	2.5 – 6.0 keV



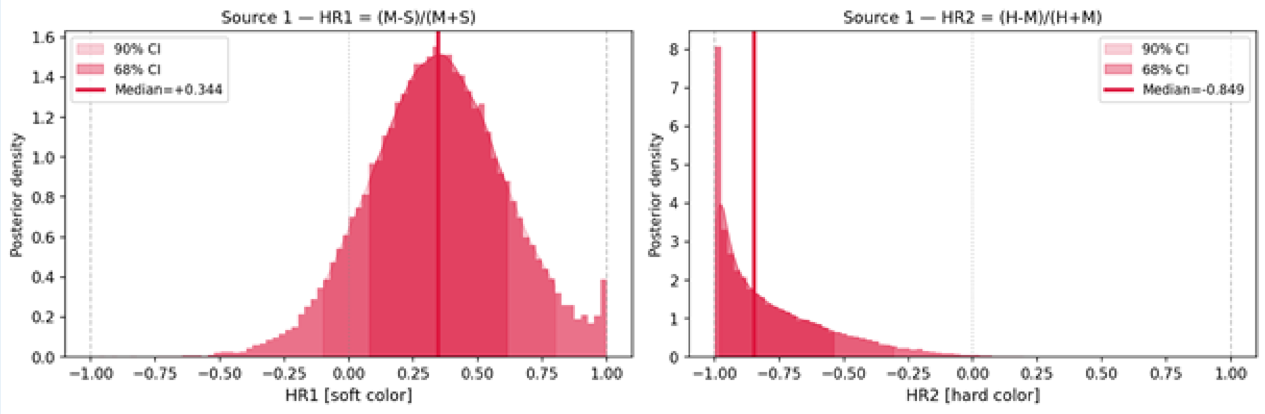
Courtesy of M. Mićić

Bayesian Estimation of Hardness Ratios (BEHR)

- BEHR uses Bayesian statistics to estimate physically meaningful hardness ratios
- Low-count X-ray observations make classical hardness ratios unreliable



- Ratios measure how photons are distributed across the energy bands



$$\mathrm{HR}_{\mathrm{ms}} = \frac{S_{mnet} - S_{snet}}{S_{mnet} + S_{snet}},$$

$$\mathrm{HR}_{\mathrm{hm}} = \frac{S_{hnet} - S_{mnet}}{S_{hnet} + S_{mnet}},$$

Disk Blackbody Model

- Modeled in Sherpa using xsdiskbb
- Assumes: optically thick (light cannot pass through), geometrically thin (physically thin) accretion disk
- Generate 300 Poisson realizations and used median value
- Accounts for statistical fluctuations in low-count X-ray data

- Parameters: temperature (tin) and normalization (disk’s geometry)
- Temperature range: 0.15 - 0.30 keV
- Normalization range: 10^{-5} – 10^{-1}

Matching models and Luminosity

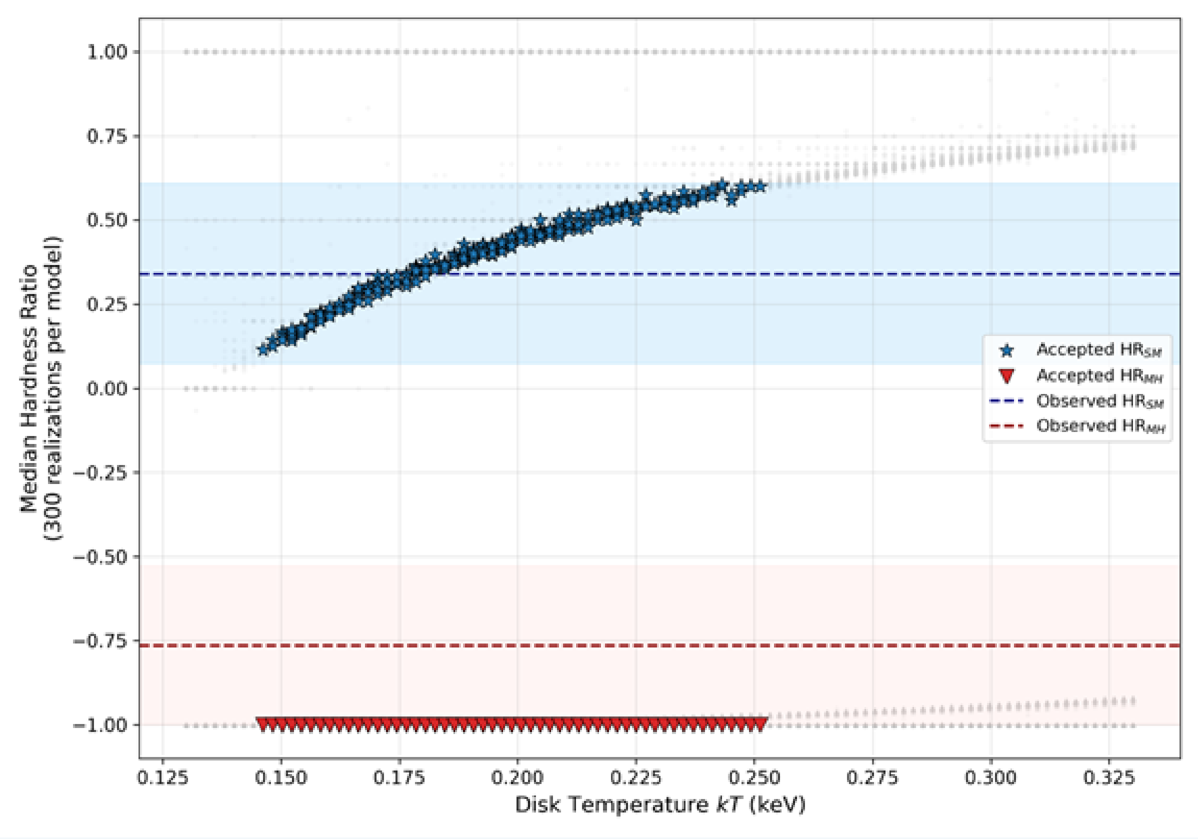
- Photon counts and hardness ratios were computed
- Compared to the baseline BEHR values
- Matching all three values = accepted model
- 58 matching models

Quantity	BEHR Range
HR_{SM}	0.073 – 0.608
HR_{MH}	−1.000 – −0.528
Total Counts	18.95 – 46.62

Table 1: BEHR hardness ratio constraints and total source counts used for comparison with simulated models.

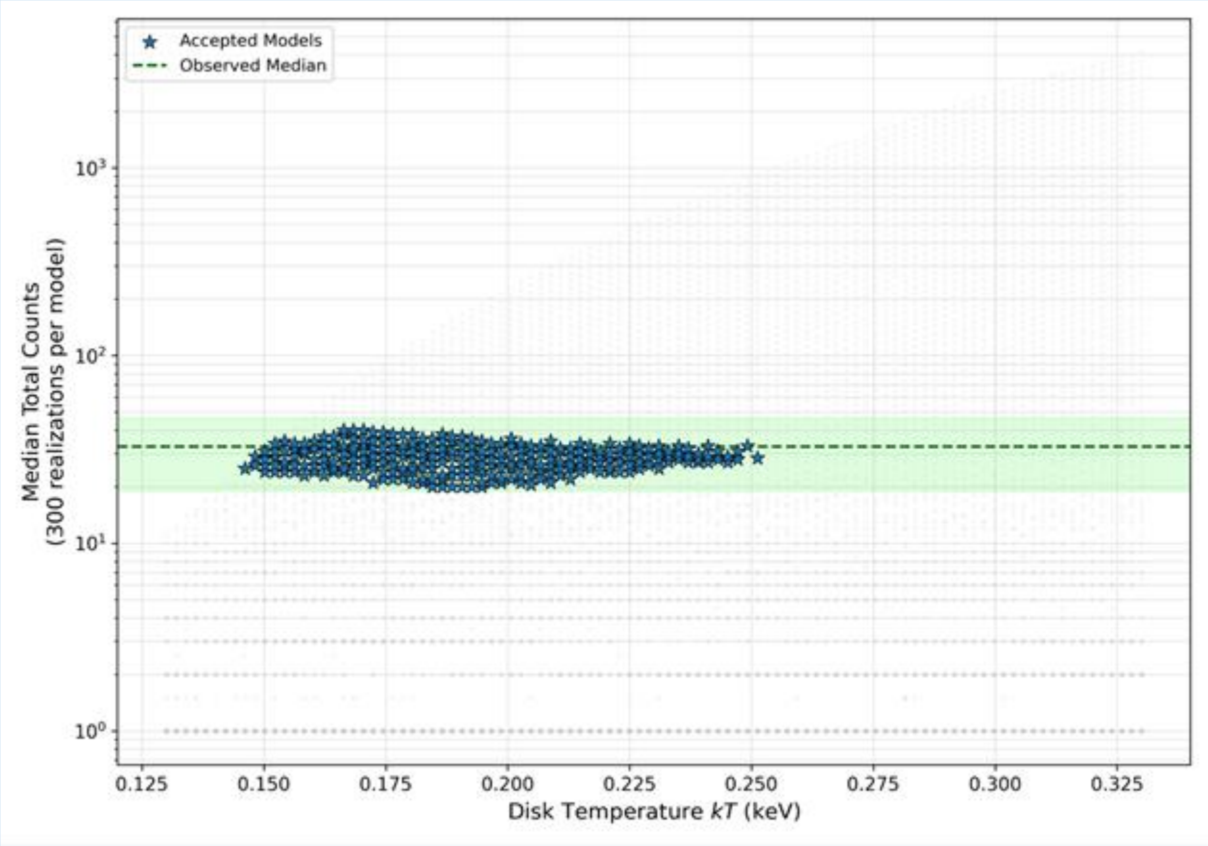
- Temperature is proportional to accretion rate and inversely proportional to mass
- One temperature value can indicate: a large, rapidly accreting black hole or small, weakly accreting black hole
- Luminosity breaks this degeneracy

HR vs. Tin



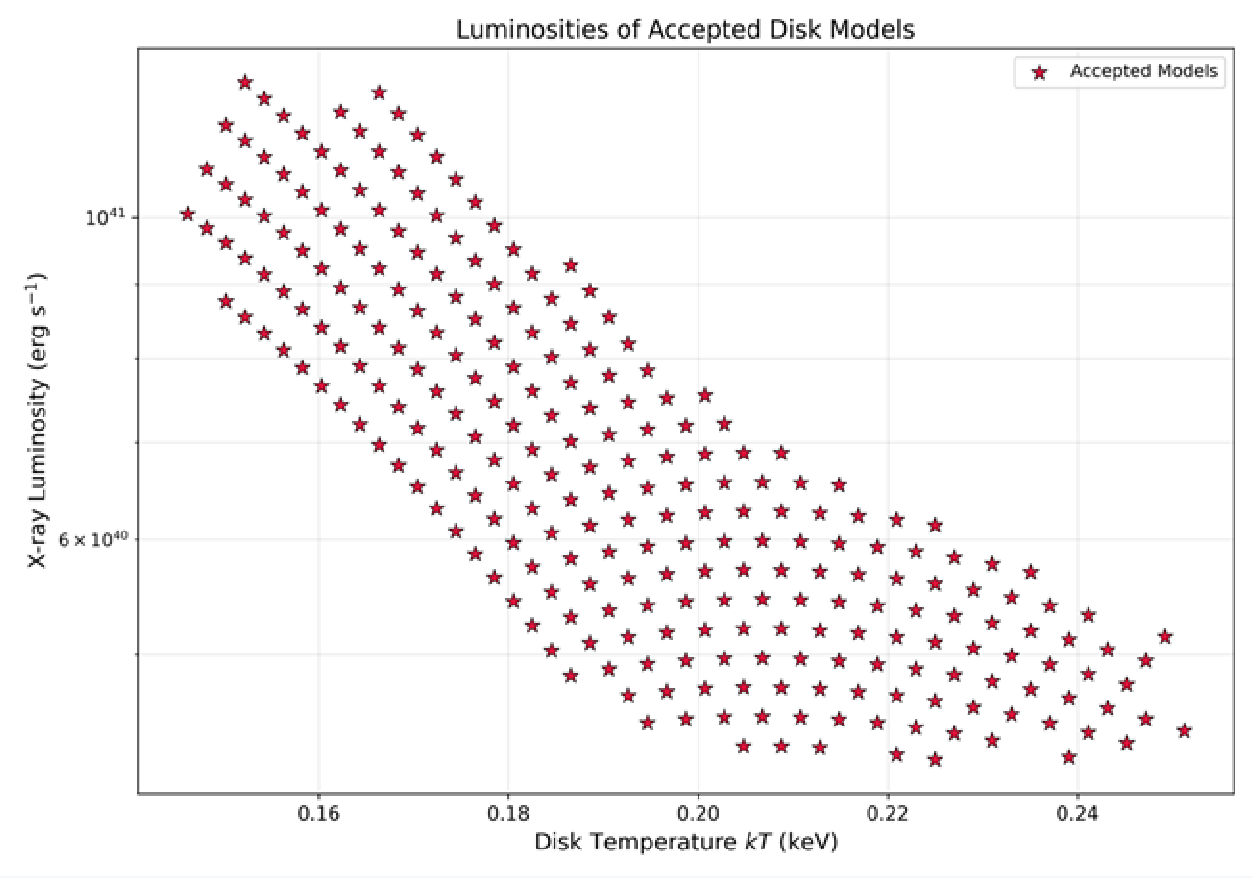
- Compares the predicted hardness ratios from each model with the BEHR hardness ratios
- Describes the shape of the spectrum
- Shaded region corresponds to the BEHR results; acceptable models must reproduce both hardness ratios simultaneously
- As Tin increases, the spectrum becomes harder
- HRMH = -1.00 and corresponds to no hard X-ray emission

Total Photon Count vs. Tin



- Graph that describes how bright the models are
- Accepted models must satisfy both hardness ratio values and total photon count

Luminosity vs. Tin



- X-ray luminosity in the rest-frame (0.3 - 6 keV)
- Range: (4.1 - 12.4) e +40 erg/s

What do the models mean physically?

- Makishima equation
- Temperature-mass-accretion rate relationship
- Combining with bolometric luminosity

$$kT_{\rm in,rest} = 1.2 \times \left(\frac{M_\bullet}{10\,M_\odot}\right)^{-1/4} \dot{m}^{1/4}\ \mathrm{keV}$$

$$L_{\rm bol} = 1.26 \times 10^{38} \times M_\bullet \times \dot{m}\ \mathrm{erg\ s^{-1}}$$

$$M_\bullet = \frac{1.44}{kT_{\rm in,rest}^2}\sqrt{\frac{10\,L_X}{1.26\times10^{38}}}\,M_\odot$$

$$\dot{m} = \sqrt{\frac{kT_{\rm in,rest}^4\,L_X}{10\times2.0736\times1.26\times10^{38}}}$$

Results

Quantity	Minimum	Maximum	Median
Black Hole Mass ($M_\odot$)	924	4210	1925
Accretion Rate ($\dot{m}$)	19.1%	40.3%	26.7%
Luminosity (10^{40} erg s^{-1})	4.1	12.4	

Table 2: Results from the accepted disk blackbody models.

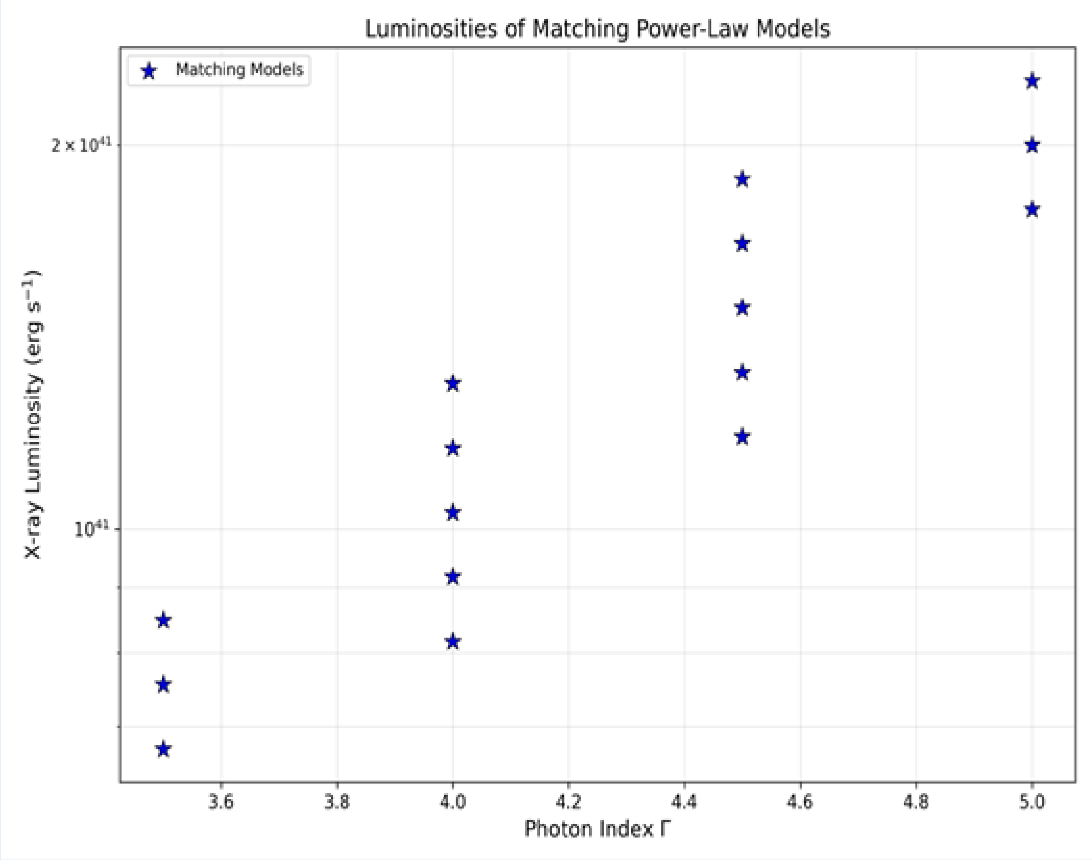
- The mass range falls within the expected range for IMBHs: one hundred to one hundred thousand solar masses

Checking using Power Law Model

- Modeled in Sherpa using xspowerlaw
- Models non-thermal X-ray emission, commonly observed in AGN via Compton upscattering
- Generate 300 Poisson realizations and used median value

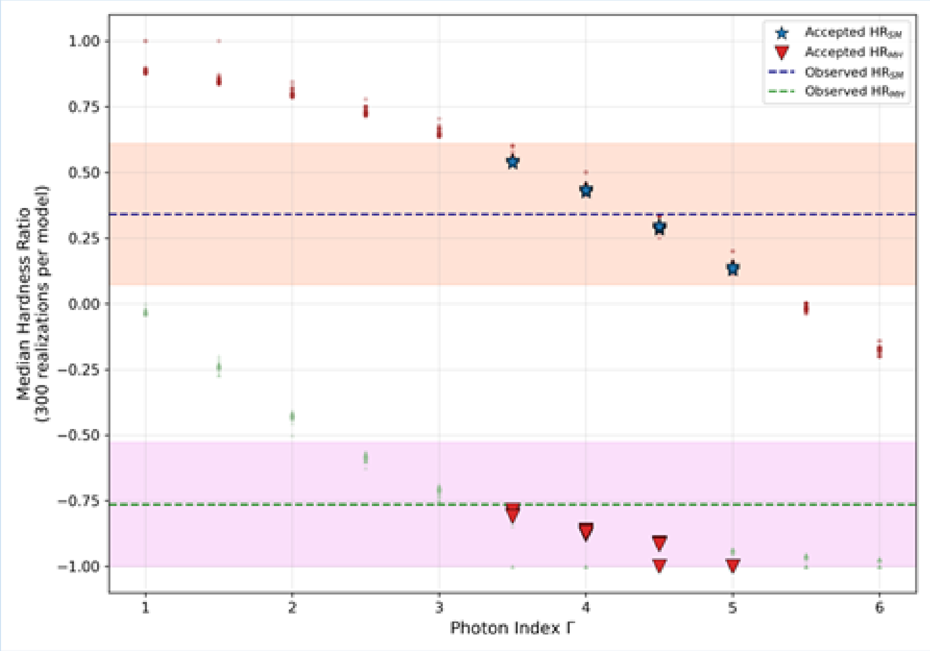
    - Parameters: photon index and normalization
    - Normalization range: 10^{-8} – 10^{-3}
    - Photon Index range: 1.00 to 6.00

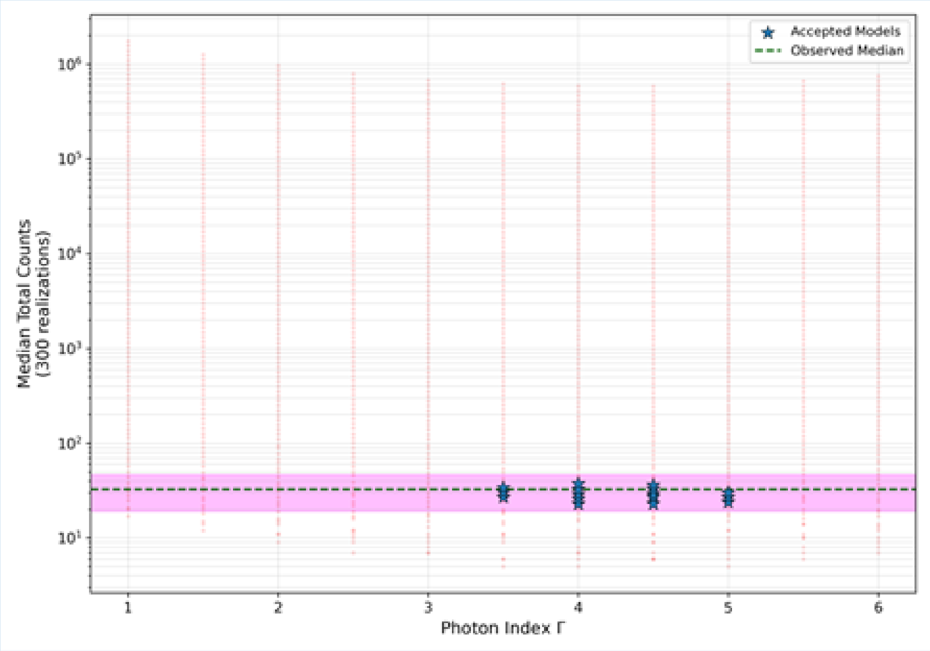
Luminosity



- Luminosities are comparable with the disk model's
- Range: (6.7 - 22.5) e +40 erg/s

Total Counts vs. Photon Index and HR vs. Photon Index





- Models with unphysically steep photon indices were accepted: normal AGN power-law spectrum does not explain observed results
- Higher gamma values correspond to higher soft X-ray emission and indicates high accretion rates
- High accretion rate implies low mass

Summary

- Mass range: 924 - 4210 M_sun
- Accreting between 19.1 - 40.3 % of Eddington limit
- Disk Blackbody and Power Law modeling both support the detection of an IMBH

Quantity	$kT_{\mathrm{in,rest}}$ **(keV)**
Minimum Mass	0.304
Maximum Mass	0.184
Minimum Accretion Rate	0.182
Maximum Accretion Rate	0.302

Table 3: Rest-frame temperatures corresponding to the accepted disk blackbody models producing the extrema.

Thank you for listening and any questions?